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PERFORMANCE PREDICTIONS FOR A
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Ski Jump Takeoff Performance Predictions for a Mixed-Flow, Remote-Lift STOVL Aircraft

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SUMMARY

A ski jump model was developed to predict ski jump takeoff performance for a short takeoff and vertical landing (STOVL) aircraft. The objective was to verify the model with results from a piloted simulation of a mixed-flow, remote-lift STOVL aircraft. This report discusses the prediction model and compares the predicted results with the piloted simulation results. The ski jump model can be utilized for basic research of other thrust vectoring STOVL aircraft performing a ski jump takeoff.

NOMENCLATURE

α	angle of attack
γ	flight path angle
δ_{CN}	cruise nozzle deflection
δ_{LN}	lift nozzle deflection
δ_{VN}	ventral nozzle deflection
$\Delta C_{L_{GE}}$	ground effect lift coefficient increment
$\Delta C_{D_{GE}}$	ground effect drag coefficient increment
$\frac{\Delta L}{T_{LN}}$	jet-induced lift increment
θ	pitch attitude angle
θ_N	deflection of the total thrust component
C_D	drag coefficient
C_L	lift coefficient
c.g.	center of gravity
D_m	inlet momentum drag
g	gravitational acceleration
K_{GE}	ground effect washout factor

\bar{q}	dynamic pressure
S	wing area
T	thrust
T_{CN}	cruise nozzle thrust
T_{LN}	lift nozzle thrust
T_{VN}	ventral nozzle thrust
W	aircraft weight
\ddot{x}	horizontal acceleration
\ddot{z}	vertical acceleration

INTRODUCTION

The U.S. and the U.K. are engaged in a joint program to develop technology for a supersonic, single-engine fighter aircraft with short takeoff and vertical landing (STOVL) capability. As part of that program recent in-house government and contracted industry aircraft design studies were conducted aimed at identifying the most promising concepts for supersonic STOVL (ref. 1). Four candidate propulsion concepts were the focus of the study: Remote Augmented Lift, Ejector/Augmentor, Hybrid Tandem Fan, and Advanced Vectored Thrust. Upon completion of the studies, a joint assessment and ranking of the concepts was conducted by a single team of officials from both nations. The overall conclusion of that assessment was that the most promising configurations are those which utilize remote lift for jet-borne flight (decoupling the location of the engine from the placement of the jet thrust nozzles) and conventional mixed-flow propulsive systems for wing-borne flight.

Ames is currently studying and evaluating a mixed-flow, remote-lift (MFRL) supersonic STOVL aircraft based on a concept recently studied by McDonnell Aircraft Company under NASA contract. The MFRL aircraft was selected because it is representative of this class of aircraft (possessing the desirable features of mixed flow for conventional flight and remote lift for powered-lift flight). In addition a simulation math model had already been prepared for a piloted fixed-base simulation conducted at Ames (ref. 2) to evaluate the transition flight envelope of the aircraft, determine the control power required during transition and hover, evaluate the aircraft's flight control and propulsion integration, and evaluate short takeoff and ski jump takeoff performance.

Prior to the piloted simulation, a ski jump model was developed to predict the MFRL aircraft transition performance during a ski jump takeoff. The main objective was to verify the model with simulation results. The verified ski jump model would then provide the capability to predict ski jump

takeoff performance and trends of other STOVL aircraft configurations, without spending the time, money, or the effort required for piloted simulations.

This report discusses the ski jump model and compares its predictions with the piloted simulation results. The report also shows the effects on the takeoff trajectory of varying the reference pitch attitude, the thrust-to-weight (T/W) ratio, the takeoff velocity, and the ramp angle.

CONCEPTUAL AIRCRAFT DESCRIPTION

The mixed-flow, remote-lift aircraft is a single-seat, single-engine STOVL fighter with supersonic dash capability. The aircraft, as shown in figure 1, has a blended wing-body configuration with a mid-mounted, diamond-planform wing, side mounted inlets, and a "V" tail.

The propulsion system concept, as illustrated in figure 2, uses a mixed-flow turbofan engine. The mixed-flow is either ducted forward to the lift nozzles and the ventral nozzle in the STOVL mode, or aft to the cruise nozzle in conventional flight. During transition from cruise to hover, the cruise nozzle is progressively closed, while the lift and ventral nozzles are opened. The cruise nozzle can be deflected $\pm 20^\circ$ in both pitch and yaw axes. The lift nozzles are variable-area, flush-mounted clam-shell nozzles and can be deflected $\pm 20^\circ$ about their nominal position 8° aft of vertical. The ventral nozzle is fixed at 8° aft of vertical. Vectored thrust is provided by a combination of vectoring the front and rear nozzle thrusts and shifting the engine flow between the lift and cruise nozzles.

SKI JUMP PILOTED SIMULATION DESCRIPTION

Piloted simulation of the mixed-flow, remote-lift aircraft was conducted on a fixed-base, single-place simulator at Ames Research Center. A continuous, three-window, computer-generated imaging system provided the external visual scene. An overhead optical combining glass projected the head-up display (HUD) for the pilot. The cockpit consisted of conventional instruments arranged similarly to the Harrier instrument panel, a center stick, and a left-hand throttle quadrant that contained both the throttle power lever and the thrust-vector deflection handle.

Three NASA pilots with V/STOL and powered-lift aircraft experience participated in the ski jump takeoff tasks. The task matrix consisted of all parameter combinations possible with two lift-nozzle deflection angles (20° , 10°), three total thrust resultant deflection angles (45° , 50° , 55°), three pitch-attitude capture angles (16° , 14° , 12°), crosswinds, and turbulence on or off. All runs were conducted at sea level on a standard day with a thrust-to-weight ratio of 0.94. The original plan was to run the full matrix on both 12° and 9° ski jump ramps.

For each task, the airplane started from engine idle and the airplane c.g. was placed a number of feet away from the start of the ski jump ramp. Launch began with application of full power. As the ramp was cleared, the pilots rotated the nozzles to the previously determined resultant thrust angle (45° , 50° , or 55°). The attitude hold system then rotated the aircraft's pitch attitude to the desired

value (16° , 14° , or 12°) within 1.5 sec. At this point in the simulation, the thrust, resultant thrust angle, and pitch angle remained constant until after the takeoff trajectory's minimum rate-of-climb point was reached. The pilots continued each run through nozzle transition until the airplane velocity was about 200 knots. Time histories of the data were recorded in real time to document the aircraft's behavior.

The pilots rated each run as acceptable or not acceptable, usually commenting on the minimum rate of climb and the acceleration performance. Each run was repeated changing the initial airplane c.g. position along the length of the runway until the pilots found the acceptable minimum operating limit of each task. This acceptable minimum operating limit was a minimum rate of climb of at least 200 ft/min (3.3 ft/s) for the takeoff trajectory. This criterion is based on the pilot's experience in fleet operations. The pilot results (shown later in this report) represent those minimum acceptable operating limits.

Each pilot did not fly the entire matrix, and due to time constraints, most of the data obtained was for the 12° ramp, and a lift-nozzle deflection angle of 20° . For the purpose of this report, only the following data with no crosswinds or turbulence are presented:

Lift nozzle, deg	Resultant thrust angle, deg	Pitch attitude, deg	Ramp angle, deg
20	45	16	12
20	50	16	12
20	55	16	12
20	45	14	12
20	50	14	12
20	55	14	12
10	45	16	12
20	45	16	9
20	50	16	9

A complete set of the piloted simulation results for the ski jump takeoffs and for conventional short takeoffs will be published in a forthcoming NASA Technical Memorandum (Samuels, J. J.; Wardwell, D. A.; Guerrero, L. M.; and Stortz, Michael W.: Simulation of Takeoff Performance of an MFRL STOVL Aircraft).

SKI JUMP PREDICTION MODEL DESCRIPTION

The ski jump model's equations of motion are written by summing the aerodynamic and propulsion forces in the horizontal and vertical directions (ref. 3). The resultant equations,

$$\ddot{x} = g \left[\left(\frac{T}{W} \right) \cos(\theta + \theta_N) - \left(\frac{qS}{W} \right) (C_L \sin \gamma + C_D \cos \gamma) - \frac{D_m}{W} \cos \gamma \right]$$

$$\ddot{z} = g \left[\left(\frac{T}{W} \right) \sin(\theta + \theta_N) + \left(\frac{qS}{W} \right) (C_L \cos \gamma - C_D \sin \gamma) - \frac{D_m}{W} \sin \gamma - 1.0 \right]$$

represent a system of two second-order, nonlinear, differential equations, which are integrated using a fixed-step, fourth-order Runge-Kutta routine. The model does not include the pitch dynamic response of the airplane but assumes that pitch attitude is a known result of pilot input and is "scheduled" accordingly (discussed further below). The model accounts for power-off aerodynamics, conventional ground effects, jet-induced effects, and propulsive forces. Inlet momentum drag (due to changes in momentum of the main inlet air flow) is also included.

The lift coefficient in the equations of motion above includes the power-off lift coefficient as a function of α , an increment for conventional ground effect, and the jet-induced (lift nozzle only) effects:

$$C_L = C_L(\alpha) + K_{GE} \Delta C_{LGE} + \frac{\Delta L}{T_{LN}} \frac{T_{LN}}{qS}$$

where

$$C_L(\alpha), K_{GE}, \Delta C_{LGE}, \text{ and } \frac{\Delta L}{T_{LN}}$$

are lookup table values (for lookup table information see refs. 2 and 4).

The drag coefficient in the equations of motion only accounts for power-off effects and consists of two terms, the drag coefficient as a function of α and an increment that accounts for the ground effect:

$$C_D = C_D(\alpha) + K_{GE} \Delta C_{DGE}$$

where

$$C_D(\alpha), K_{GE}, \text{ and } \Delta C_{DGE}$$

are lookup table values (for lookup table information see ref. 2).

The propulsion portion of the model accounts for the normal and axial forces due to thrust vectors at the lift nozzle, the ventral nozzle, and the cruise nozzle:

$$T_{\text{normal}} = T_{\text{LN}} \cos(\delta_{\text{LN}} + 8^\circ) + T_{\text{VN}} \cos(\delta_{\text{VN}}) + T_{\text{CN}} \sin(\delta_{\text{CN}})$$

$$T_{\text{axial}} = T_{\text{LN}} \sin(\delta_{\text{LN}} + 8^\circ) + T_{\text{VN}} \sin(\delta_{\text{VN}}) + T_{\text{CN}} \cos(\delta_{\text{CN}})$$

$$\text{Thrust} = \sqrt{T_{\text{axial}}^2 + T_{\text{normal}}^2}$$

The model begins simulation at launch from the ski jump ramp, and does not simulate the ski jump deckrun (i.e., at $t = 0.0$ sec the airplane, represented by a point mass at the c.g., is at the end of the ramp). Emulating the piloted simulation, the weight, thrust, and nozzle deflection angles are assumed constant in the prediction model during the initial phase of the flyaway trajectory. Pitch is "scheduled" from the initial pitch attitude to the reference pitch attitude in 1.5 sec, and then held constant. Deckrun distance is calculated after the takeoff velocity is known. The model provides time histories for all runs.

The model can be used in two different ways. The model can read a set of initial conditions from a file and iterate in a given velocity-search range until it finds the takeoff velocity whose trajectory produces the desired minimum rate of climb. Otherwise, a desired takeoff velocity can be specified, and the resulting trajectory and minimum rate of climb are generated.

To find the takeoff velocity which will produce a desired rate of climb given a set of conditions, the initial condition file consists of: weight; lift-, cruise-, and ventral-nozzle thrusts and their respective deflection angles; initial aircraft pitch attitude; ski jump ramp deflection angle; desired minimum rate of climb; and a range of takeoff velocities (which the program uses to run a set of ski jump trajectories in search of the desired minimum rate of climb). When a specific takeoff velocity is desired, the initial input is the same as above, except only one takeoff velocity is input to the file and no minimum rate of climb information is provided. If the initial lift-, cruise-, and ventral-nozzle thrust and deflection angle information is not available, an alternate input scheme using the total thrust, thrust split, and the lift- and cruise-nozzle deflection angles can also be used. The initial pitch attitude at the end of the ramp is determined from the inclination of the ramp (9° or 12°), and the inclination of the aircraft at compressed gear height.

The ski jump takeoff prediction scheme used (holding weight, thrust, resultant thrust angle, and captured pitch attitude constant) is valid only during the transition segment of the ski jump takeoff (this includes the minimum rate of climb point). The prediction scheme is not valid after nozzle transition has begun, since the assumptions of constant thrust, thrust resultant angle, and pitch attitude are no longer valid.

RESULTS

The predictions presented all use initial conditions from the simulation data for the lift-, cruise- and ventral-nozzle thrusts and their respective deflection angles. Prior to the simulation, the thrust and nozzle information required for the initial input conditions was obtained from NASA Ames' takeoff model for short takeoff (STO). Correct trends were predicted using this early data. However,

those predictions were not as close to the pilot results as the predictions obtained when the initial thrust conditions came from the simulation data.

The most interesting results obtained from a ski jump takeoff simulation are the takeoff distance and takeoff velocity required to achieve a desired minimum rate of climb (ROC). As the ski jump ramp exit velocity is decreased, the minimum ROC during the ski jump flyaway decreases. The predicted minimum ROC as a function of ramp exit velocity for the mixed-flow, remote-lift (MFRL) aircraft is shown for nine test cases in figures 3-6. Pilot results are also shown in those figures for comparison. The trends indicated by the prediction model results are in good agreement with the pilot results. The pilot scatter is affected by the rate at which full throttle was applied, and the actual time when the nozzles were deflected as the ramp was cleared.

Figure 7 shows predicted and pilot scaled takeoff distances for the 12° ramp as a function of takeoff velocity. The takeoff distances are referenced to an arbitrary point to keep the data unclassified. The two lines are simple curve fits of the pilot and the predicted takeoff distances for the same test cases shown in figures 3, 4, and 6. Comparing both curve fits shows that the actual takeoff distances were less than the predicted takeoff distances by about 5-10 ft.

The takeoff velocity and ground roll predictions for the MFRL aircraft (for a specified minimum ROC ski jump takeoff trajectory) are summarized and compared to the pilot results in tables 1-4. Tables 1 and 2 summarize and compare the predicted and the pilot results for the test cases presented in figures 3 and 4 (20° lift-nozzle, 12° ramp, and 16° and 14° pitch attitudes). The average difference in table 1 between the predicted and the pilot results was 1 knot for the takeoff velocity and 7 ft for the takeoff distance. The average difference in table 2 between the predicted and the pilot results was 0.3 knots for the takeoff velocity and 5 ft for the takeoff distance.

Table 3 summarizes the results of the test case presented in figure 5 (20° lift-nozzle, 9° ramp). The average difference in table 3 between the predicted and the pilot results was 2 knots for the takeoff velocity and 3 ft for the takeoff distance.

Table 4 summarizes the results of the test case presented in figure 6 (10° lift-nozzle, 12° ramp). The average difference in table 4 between the predicted and the pilot results was 1 knot for the takeoff velocity and 13 ft for the takeoff distance.

The ski jump prediction model also generates time histories. The time histories shown in figure 8 for velocity, rate of climb, altitude, and pitch attitude compare simulation and predicted data for the case of a 12° ski jump, 20° lift-nozzle deflection angle, 45° resultant thrust angle, 16° reference attitude, and 52 knots takeoff velocity (see fig. 3, $\theta_N = 45^\circ$). Time zero is at the moment the airplane leaves the ramp. The prediction model can provide other time histories not shown in figure 8 (such as flight path angle, angle of attack, acceleration along the flight path, and thrust components) as required.

Table 1. Summary of predicted results compared to pilot results for a given minimum rate of climb flyaway trajectory

Lift nozzle angle = 20° 12° ski jump, T/W = 0.94 Pitch attitude capture of 16°			
θ_N , deg	Takeoff velocity, knots (prediction/pilot)	Distance, ft* (prediction/pilot)	Minimum rate of climb, ft/sec
45	52/52	73/66	4.0
45	51/52	68/63	3.5
45	51/51	68/67	3.5
50	49/52	58/57	4.0
50	50/51	63/54	4.5
50	50/51	63/56	4.5
50	49/49	58/54	4.0
50	47.5/49	51/43	3.0
50	52/53	73/56	6.0
55	47.3/48	50/44	4.5
55	48/49	54/44	5.0

*Scaled ground-roll distance.

Table 2. Summary of predicted results compared to pilot results for a given minimum rate of climb flyaway trajectory

Lift nozzle angle = 20° 12° ski jump, T/W = 0.94 Pitch attitude capture of 14°			
θ_N , deg	Takeoff velocity, knots (prediction/pilot)	Distance, ft* (prediction/pilot)	Minimum rate of climb, ft/sec
45	55/55	88/83	3.5
50	51.5/52	70/67	3.5
50	50.7/52	67/63	3.0
50	51/51	68/66	3.25
55	47.7/48	52/44	3.0
55	51.5/51	70/66	5.25
55	51.8/52	72/63	5.5

*Scaled ground-roll distance.

Table 3. Summary of predicted results compared to pilot results for a given minimum rate of climb flyaway trajectory

Lift nozzle angle = 20° 9° ski jump, T/W = 0.94 Pitch attitude capture of 16°			
θ_N , deg	Takeoff velocity, knots (prediction/pilot)	Distance, ft* (prediction/pilot)	Minimum rate of climb, ft/sec
45	55/56	86/90	4.5
50	50.5/54	64/72	3.5
50	51/53	66/68	3.75
50	51.5/53	69/69	4.0

*Scaled ground-roll distance.

Table 4. Summary of predicted results compared to pilot results for a given minimum rate of climb flyaway trajectory

Lift nozzle angle = 10° 12° ski jump, T/W = 0.94 Pitch attitude capture of 16°			
θ_N , deg	Takeoff velocity, knots (prediction/pilot)	Distance, ft* (prediction/pilot)	Minimum rate of climb, ft/sec
45	59/58	110/94	3.75
45	60/61	116/107	4.5
45	60.5/61	119/106	4.75

*Scaled ground-roll distance.

DISCUSSION OF RESULTS

Comparing figures 3 and 4 (16° and 14° reference attitudes, respectively), one can see that a takeoff velocity of 3-4 knots higher is required for the lower reference attitude to achieve the same takeoff performance. This corresponds to about a 20 ft increase in the takeoff distance. Thus, holding resultant thrust angle, takeoff velocity, and T/W constant, a higher reference attitude produces a flyaway trajectory with improved minimum rate of climb.

Reducing lift nozzle deflection from 20° to 10° (see figs. 3 and 6) lowers the trajectory minimum rate of climb for a given takeoff velocity and reference attitude. The lower lift nozzle setting requires about 7 knots higher takeoff velocity and about 40 ft more takeoff distance to get similar takeoff performance.

The 9° ski jump ramp requires about 2 knots higher takeoff velocity and about 10 ft more takeoff distance than the 12° ramp to get similar takeoff performance (see figs. 3 and 5).

The best combination of parameters examined in this report (figs. 3-7) for a ski jump takeoff with acceptable minimum rate of climb (3.3 ft or higher) is the higher lift nozzle deflection (20°), the higher reference attitude (16°), and the higher ski jump ramp (12°). The pilot results are in agreement with these conclusions.

ADDITIONAL PREDICTIONS

Since the ski jump model compares well with the pilot results, we are now able to make some predictions for the mixed-flow, remote-lift aircraft (or any other STOVL type aircraft we wish to model) during a ski jump takeoff. Typical ski jump takeoff trajectories, and in some cases velocity time histories, are presented for the mixed-flow, remote-lift aircraft to illustrate the effects of varying the following variables: pitch attitude, T/W ratio, takeoff velocity, and ramp angle. These effects are shown in figures 9-12. Although many of the predicted effects seem intuitively obvious, the model allows us to quantify the effects of varying parameters for the modeled aircraft.

In figure 9, ski jump flyaway trajectories resulting from takeoff velocities of 40, 50, and 60 knots are shown for the same conditions of figure 3 at $\theta_N = 45^\circ$. These trajectories have a minimum rate of climb of about -3, 3, and 9 ft/sec, respectively. Using this figure, obstacle clearance can be evaluated as a function of the takeoff speed. For example, if the pilot needs to clear a 50 ft obstacle 600 ft away from the ramp exit, a takeoff velocity of 50 knots or higher is required. The excess capability shown for a takeoff speed of 60 knots is available but requires additional takeoff ground-roll distance.

Figure 10 shows the effect of varying the ski jump ramp angle. For a constant takeoff velocity, a higher ramp angle provides a better flyaway trajectory. This also means that for the same trajectory, as the ski jump ramp angle is increased (up to a practical limit, ref. 4), the launch velocity can be decreased, resulting in shorter takeoff distances.

Figure 11 shows the effect of different reference attitudes on velocity and flight path trajectory. There is less altitude loss for the higher reference attitudes, but higher reference attitudes cause a loss in velocity. The choice of whether to have excess altitude or higher velocity during the flyaway trajectory depends on the individual pilots. One of the pilots in the simulation preferred a lower pitch attitude (14° instead of 16°) because of improved forward visibility. These pilot opinions may be different for a moving-base simulation.

Figure 12 shows the effect of varying the T/W ratio. Keeping the ramp angle and the takeoff velocity constant, the higher T/W ratios give higher performance margins. Simply stated, to keep the same performance margin, the higher T/W ratios require less takeoff velocity and less takeoff distance.

CONCLUSIONS

A ski jump prediction model was developed to predict ski jump takeoff performance for a short takeoff and vertical landing (STOVL) aircraft. The takeoff performance results obtained with the ski jump prediction model agree well with the piloted fixed-base simulation results of the mixed-flow, remote-lift aircraft. In addition, the model can be used to predict trends such as the effect of ramp angle, the effect of various T/W ratios, or the effect of body attitude on transition, as demonstrated in the report. The model can easily be utilized to make predictions for other STOVL concepts performing ski jumps.

REFERENCES

1. Levine, J.; and Inglis, M.: US/UK Advanced Short Takeoff and Vertical Landing Program (ASTOVL). AIAA Paper 89-2039, 1989.
2. Engelland, S. A.; Franklin, J.; and McNeill, W.: Simulation Model of a Mixed-Flow Remote-Lift STOVL Aircraft. NASA TM-102262, 1990.
3. Kohlman, D. L. : Introduction to V/STOL Airplanes. Iowa State University Press, Ames, Iowa, 1981.
4. Wardwell, D. A.: Jet Induced Effects for the MFRL STOVL Simulation Model. NASA TM-102858, 1991.

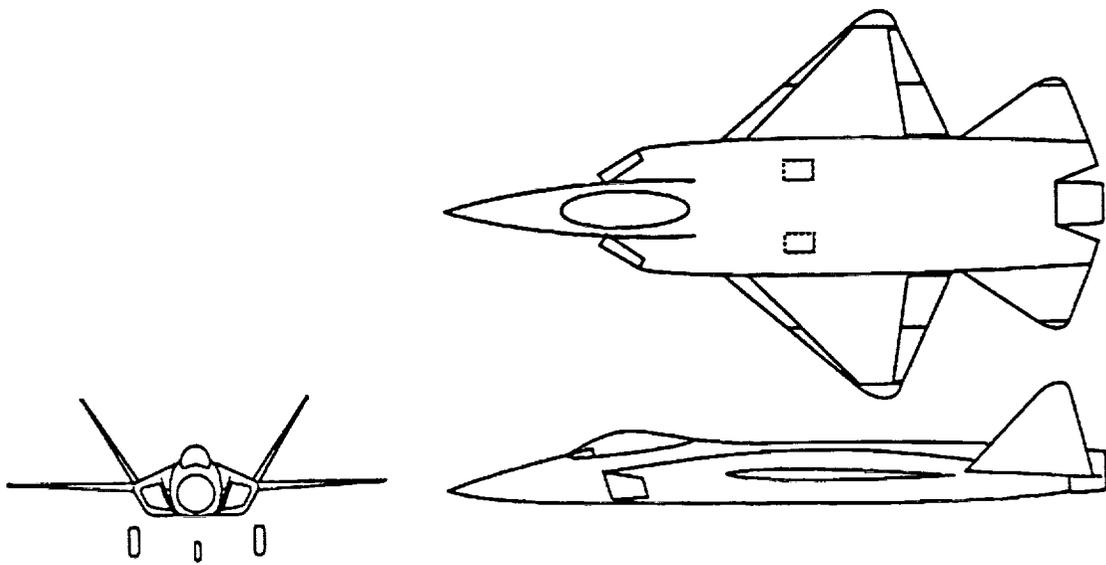


Figure 1. Mixed-flow remote-lift STOVL aircraft.

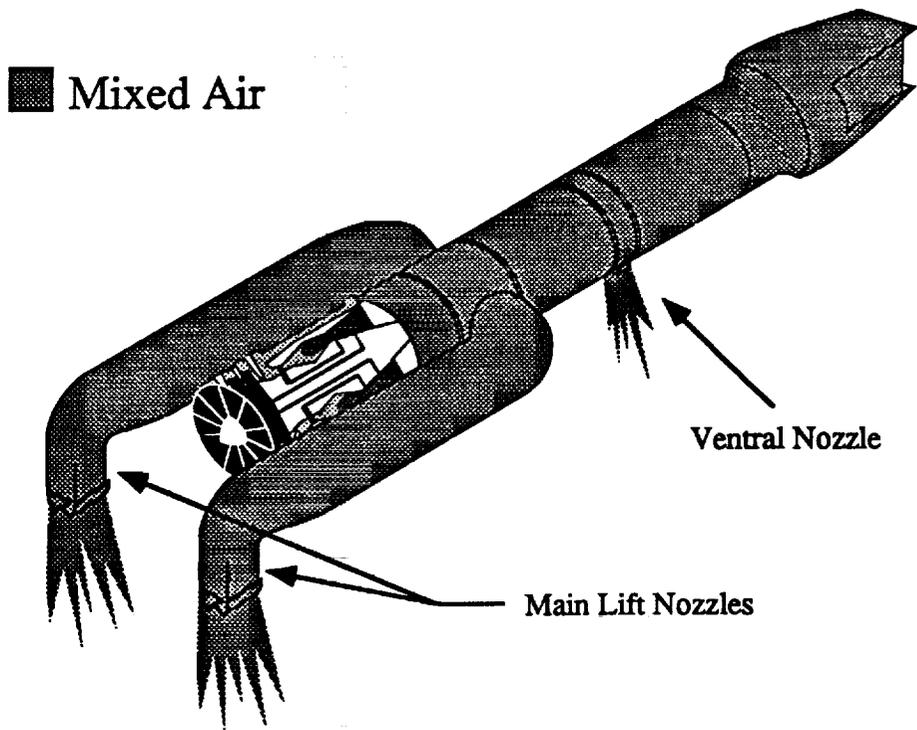
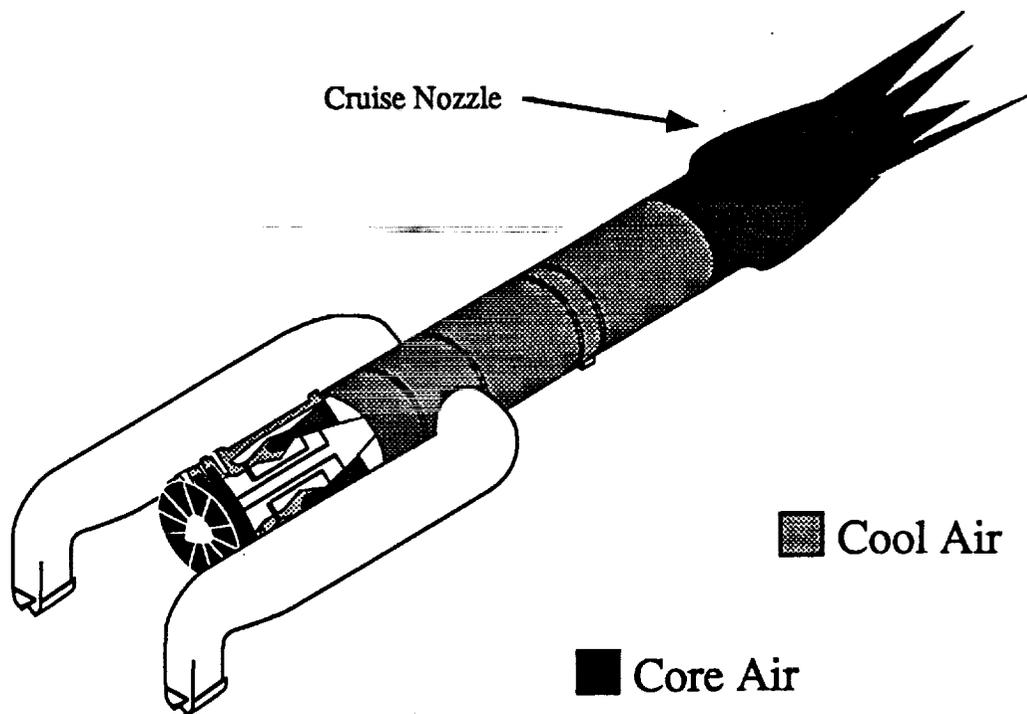


Figure 2. Mixed-flow remote-lift propulsion system.

Lift Nozzle Angle = 20°
 Pitch Attitude Capture = 16°
 T/W = 0.94 12° Ski Jump

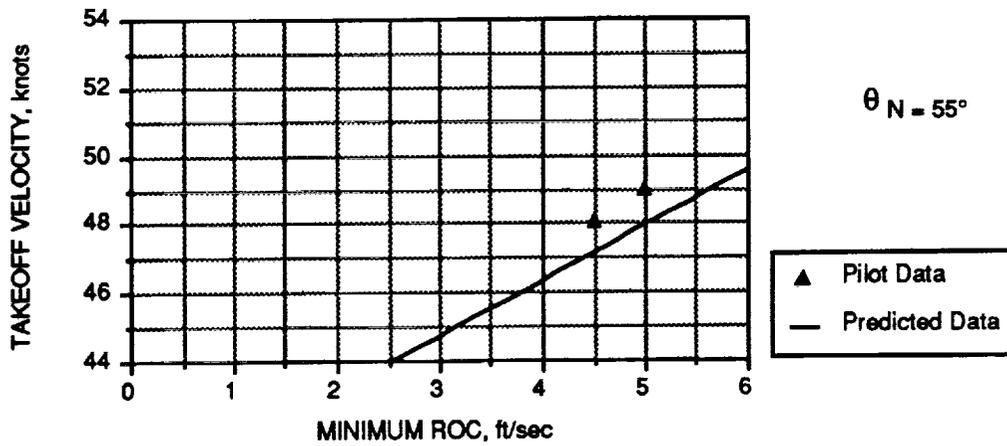
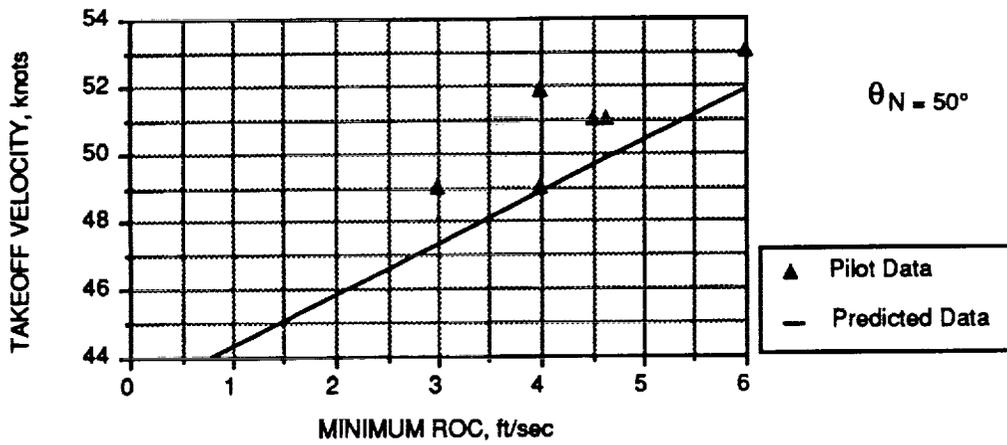
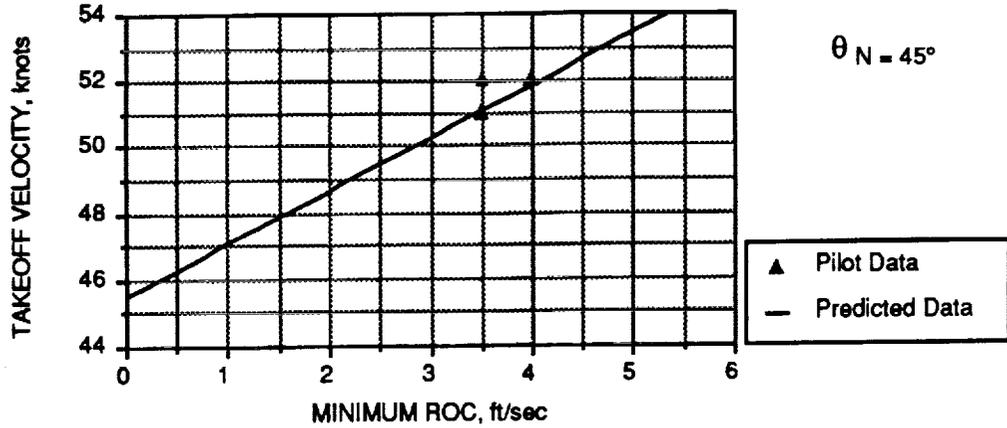


Figure 3. Minimum rate of climb during ski jump takeoff.

Lift Nozzle Angle = 20°
 Pitch Attitude Capture = 14°
 T/W = 0.94 12° Ski Jump

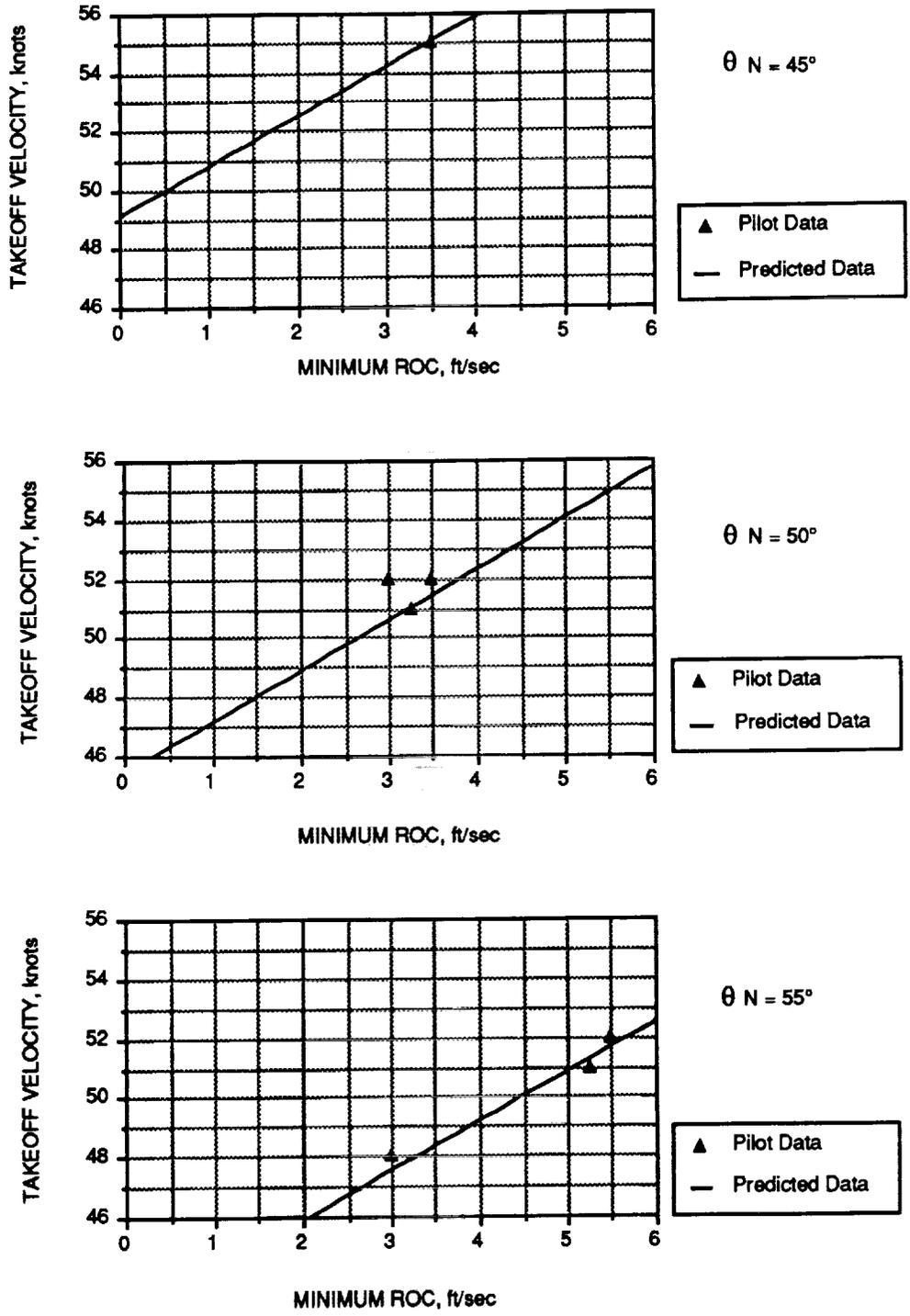


Figure 4. Minimum rate of climb during ski jump takeoff.

Lift Nozzle Angle = 20°
 Pitch Attitude Capture = 16°
 T/W = 0.94 9° Ski Jump

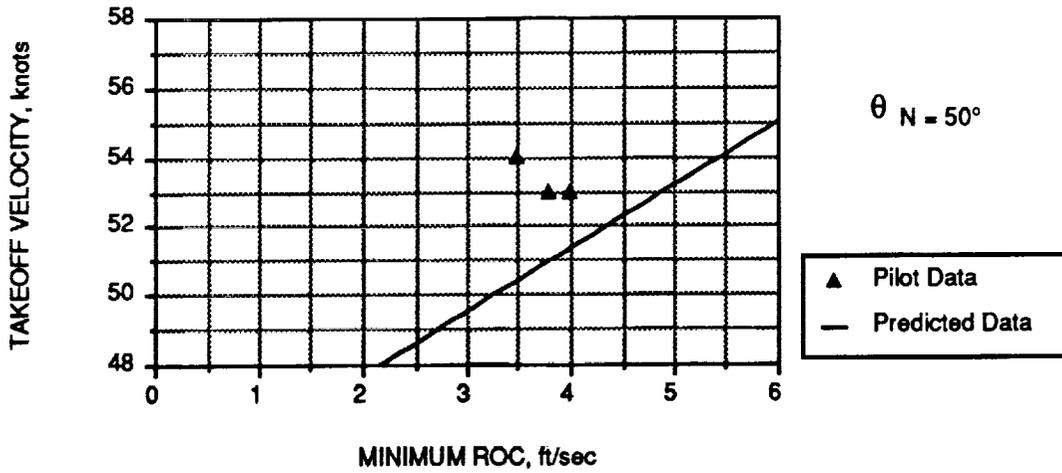
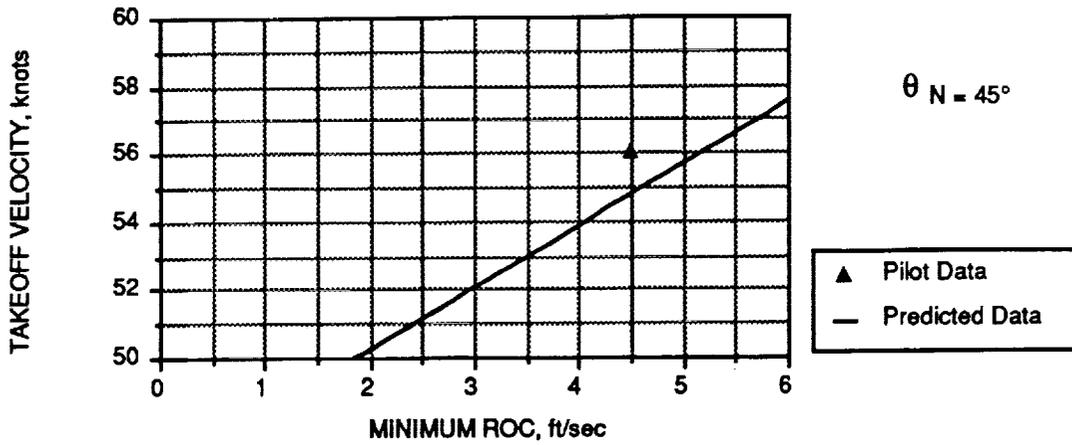


Figure 5. Minimum rate of climb during ski jump takeoff.

Lift Nozzle Angle = 10°
 Pitch Attitude Capture = 16°
 T/W = 0.94 12° Ski Jump

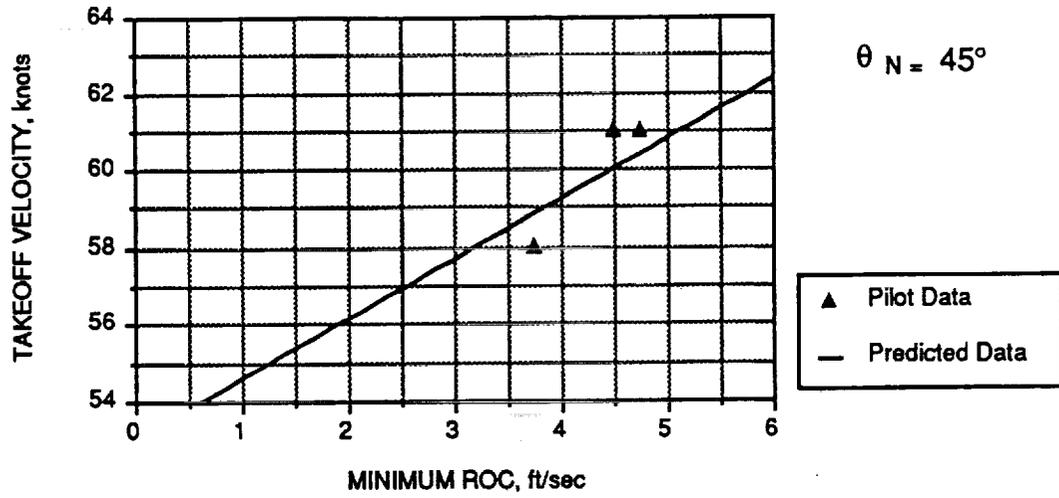


Figure 6. Minimum rate of climb during ski jump takeoff.

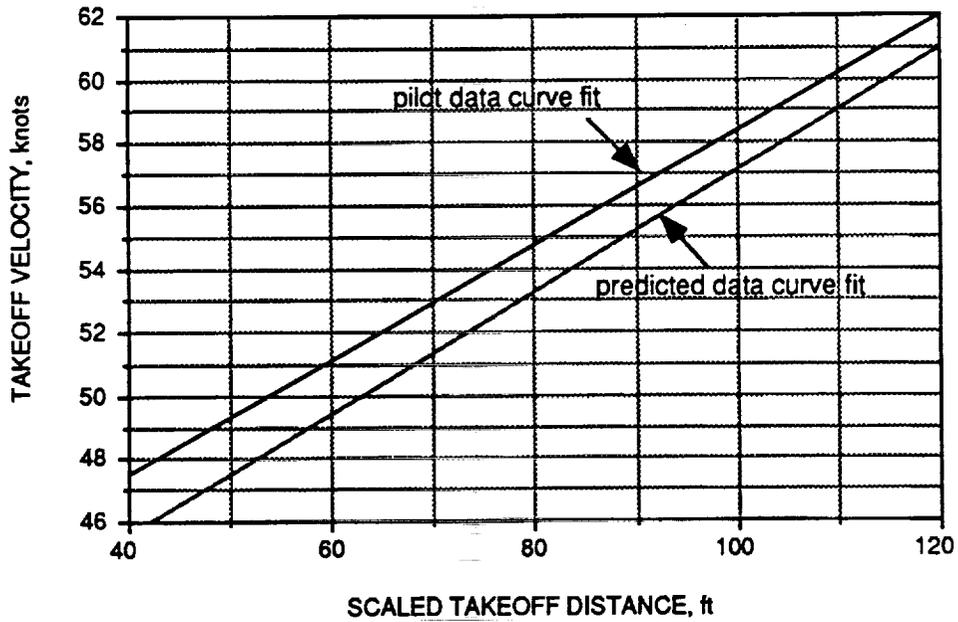


Figure 7. Scaled takeoff distances for 12° ramp.

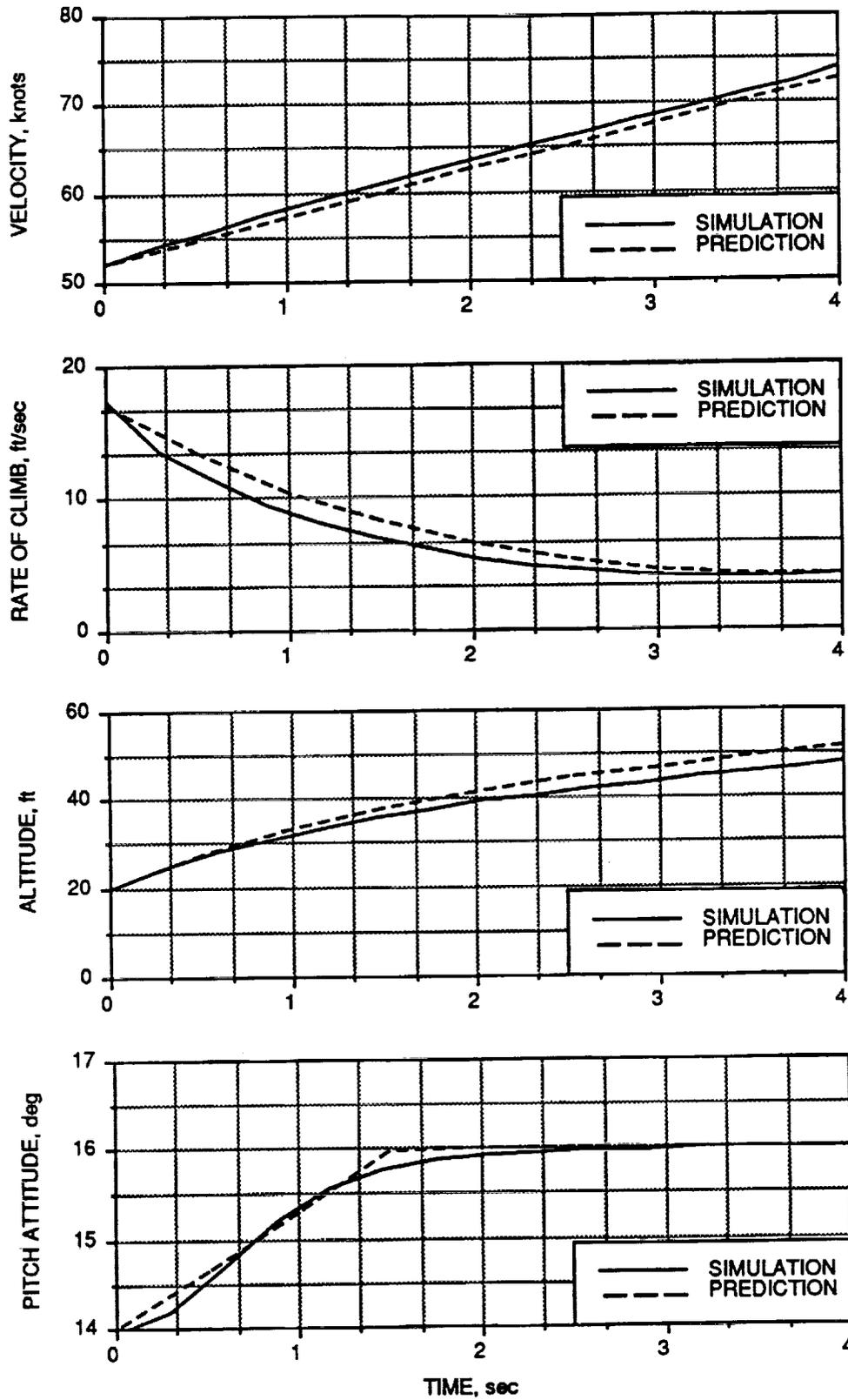


Figure 8. Time history example.

Thrust Resultant Angle = 45° T/W = 0.94
 Lift Nozzle Angle = 20° Ramp Angle = 12°
 Pitch Attitude Capture = 16°

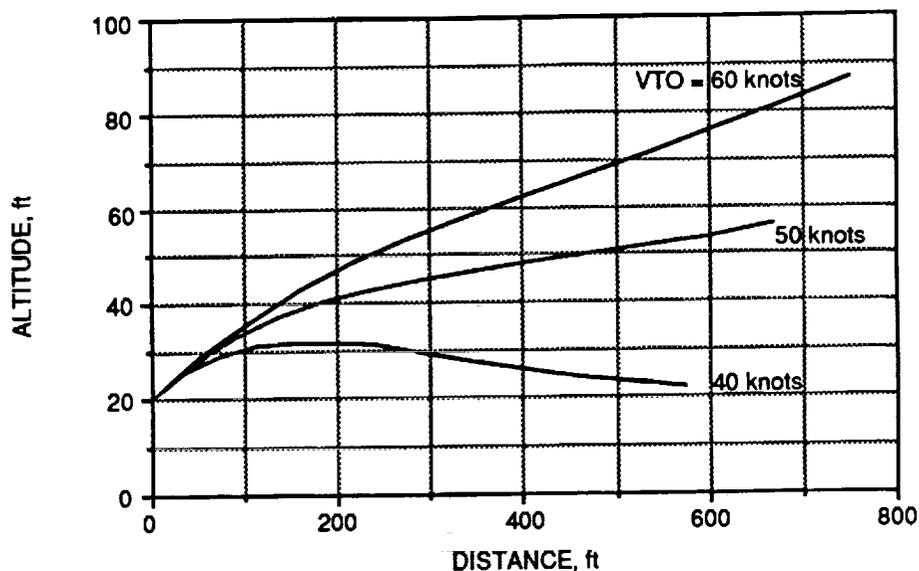


Figure 9. Effect of takeoff velocity on ski jump trajectory.

Thrust Resultant Angle = 45° T/W = 0.94
 Lift Nozzle Angle = 20° Takeoff Velocity = 51 knots
 Pitch Attitude Capture = 16°

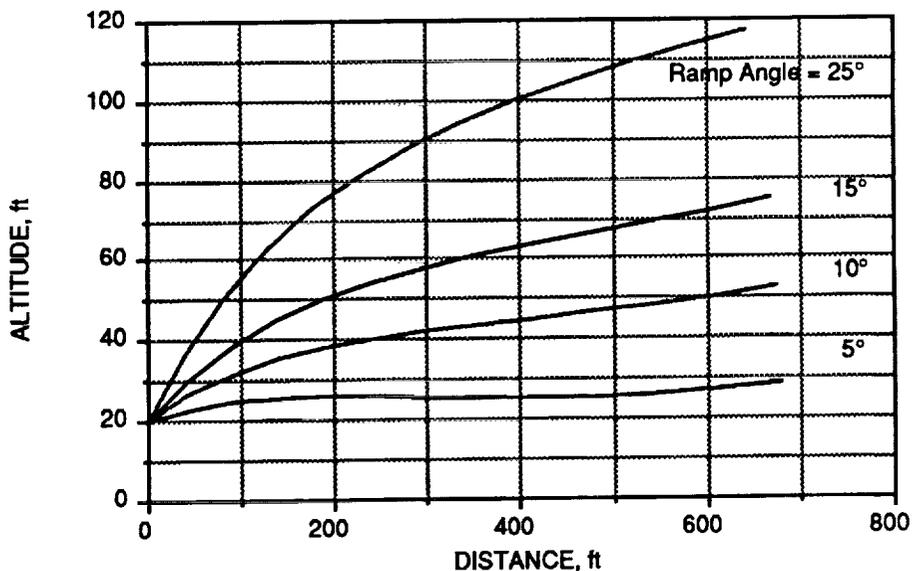


Figure 10. Effect of ramp angle on ski jump trajectory.

Thrust Resultant Angle = 45° T/W = 0.94
 Lift Nozzle Angle = 20° Ramp Angle = 12°
 Takeoff Velocity = 54 knots

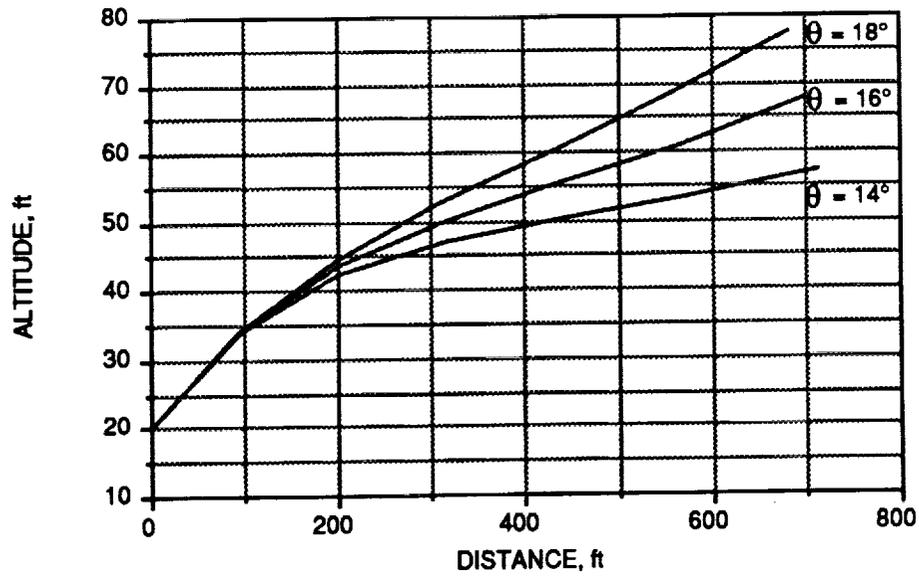
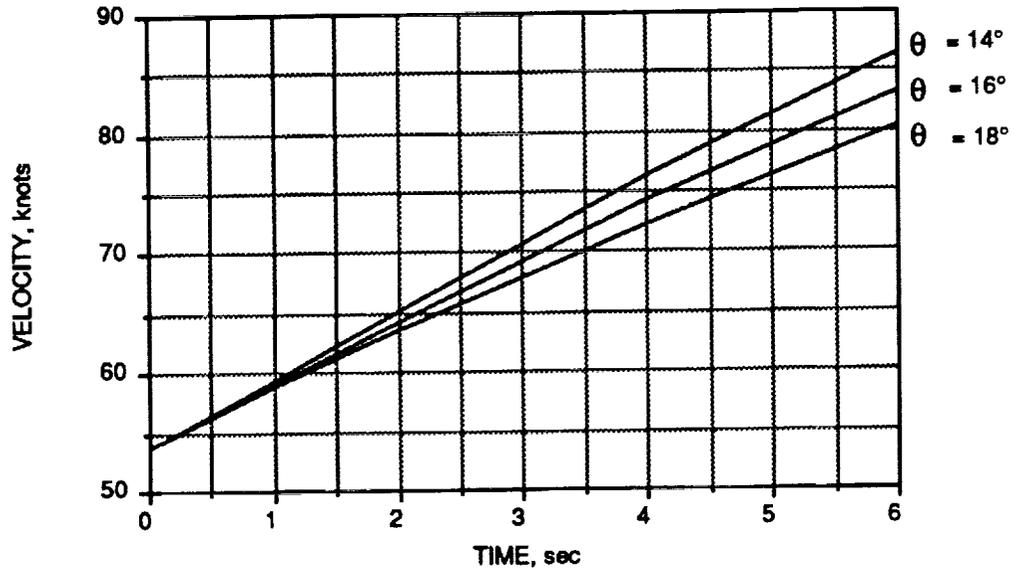


Figure 11. Effect of pitch attitude on ski jump performance.

Thrust Resultant Angle = 45°
 Lift Nozzle Angle = 20° Ramp Angle = 12°
 Pitch Attitude Capture = 16° Takeoff Velocity = 54 knots

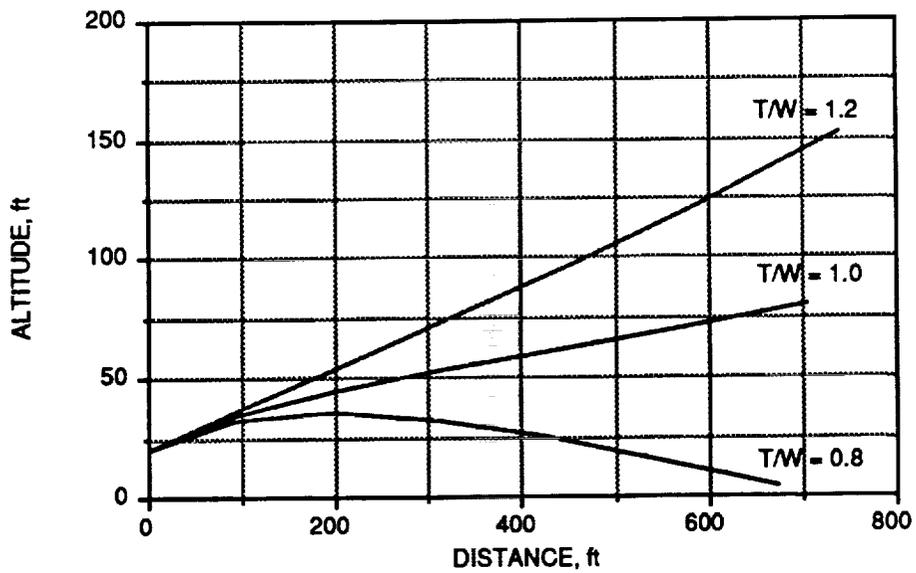
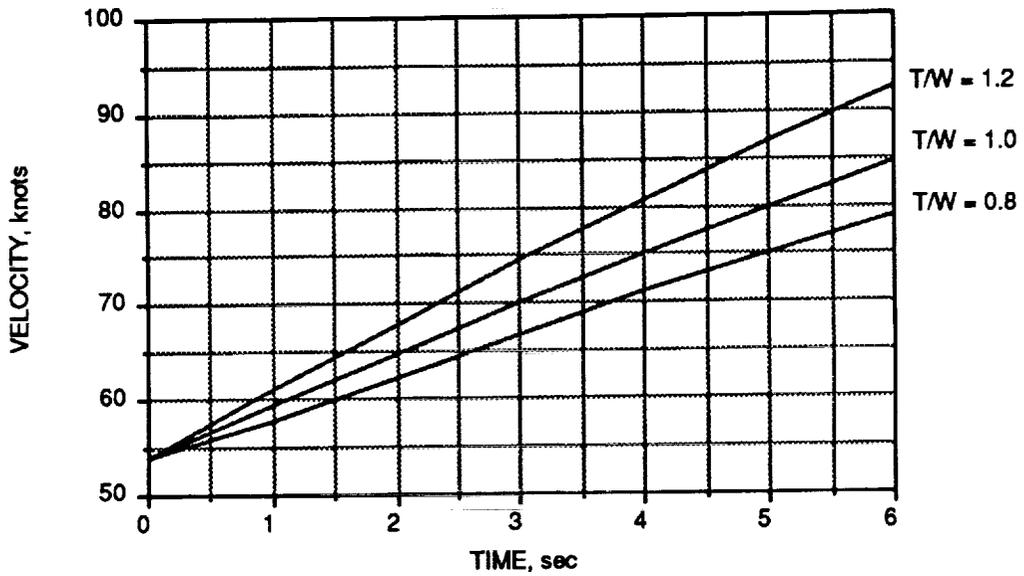
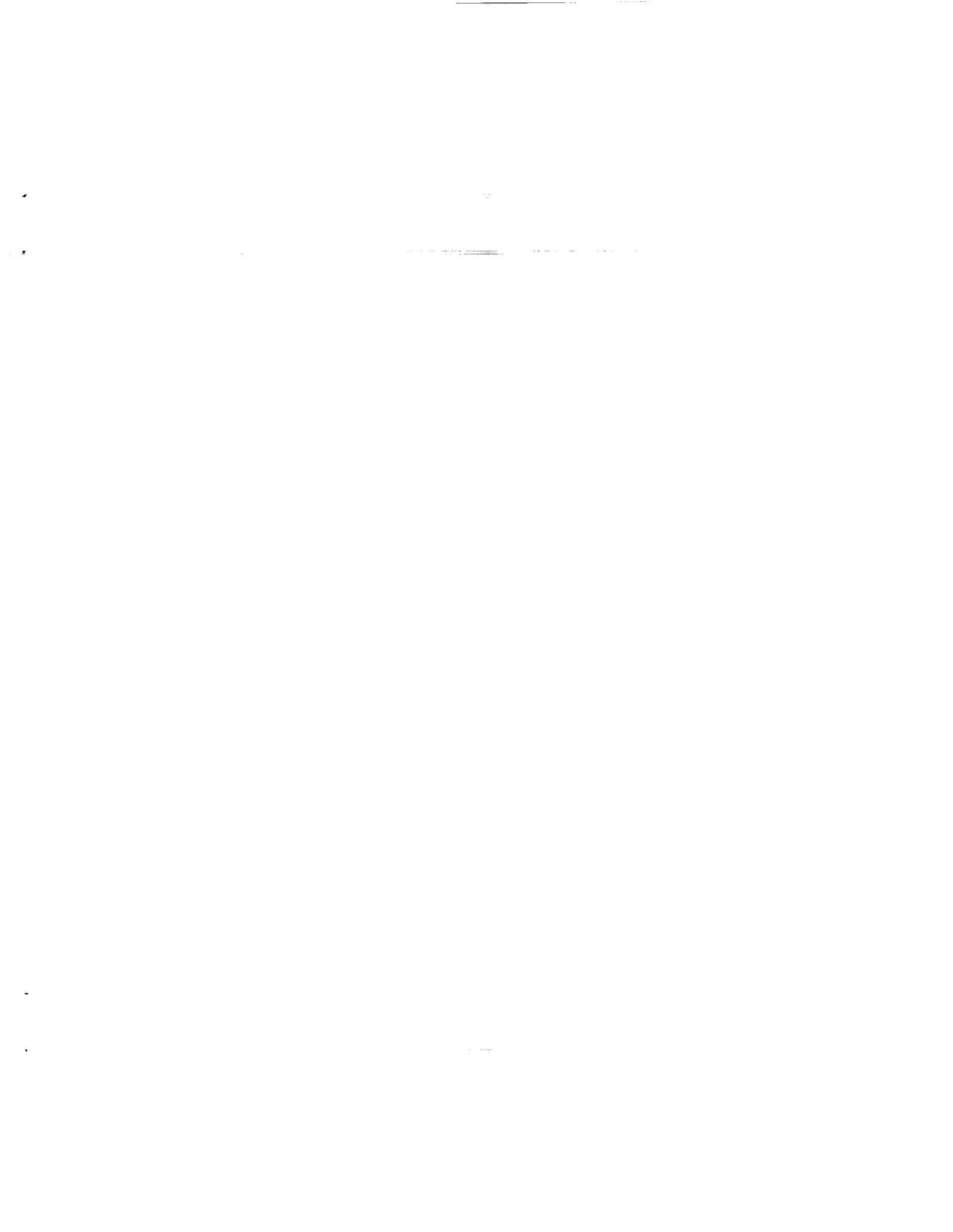


Figure 12. Effect of thrust/weight on ski jump performance.





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